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Project Report

EU—Africa: Digital and Social Questions in a Multicultural Agroecological Transition for the Cocoa Production in Africa

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Abstract: The challenge of this century is without a doubt to counter global warming. Land management, agriculture, and forests are responsible for 23% of total greenhouse gases (GHGs). In developing countries, such as those in African territories, where economic capacities are sometimes small and socio-cultural and linguistic perceptions are different, this requires a transition that is just and respectful of local culture and language, while at the same time helping to create labor conditions that respect gender and minors. This article describes a socio-technical ecological transition in the cocoa chain production in Côte d'Ivoire, which is not only the world's leading producer of cocoa beans (45%) but also one of the African countries most prone to deforestation. Linguistic and multicultural aspects come together in Côte d'Ivoire, where more than 70 local languages are spoken. Intelligent digital approaches, agroecological issues, new methods, and sociocultural questions are embedded in a context of collaboration and co-creation, a living lab approach, to ensures sharing and co-creation among NGOs, farmers, companies, and researchers. A framework of socio-technical transition is presented, and this research aims to not only achieve the goals of a just ecological transition and reduce carbon footprint and deforestations but also to create diverse labour conditions, gender respect and inclusion.

Keywords: Africa; cocoa; socio-technical transition; global warming; just transition; sensors; satellites; machine learning; multilinguistic; multicultural

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Citation: Pinardi, Stefano, Matteo Salis, Gabriele Sartor, and Rosa Meo. 2023. EU—Africa: Digital and Social Questions in a Multicultural Agroecological Transition for the Cocoa Production in Africa. *Social Sciences* 12: 398. https://doi.org/10.3390/socsci12070398

Academic Editors: Kittisak Jermsittiparsert, Ismail Suardi Wekke, Oytun Sozudogru and Jamaluddin Ahmad

Received: 15 May 2023
Revised: 28 June 2023
Accepted: 2 July 2023
Published: 7 July 2023

1. Introduction

The fight against climate change is a global problem that requires the involvement of many different actors, with different capacities and different competing practical goals.

A long scientific debate has ensued regarding the causes of current climate change, specifically whether it is primarily due to human activities (anthropogenic change) or influenced by natural factors. Unfortunately, public discussions on this matter have often lacked impartiality, with the mainstream media emphasizing dialectic conflicts for sensationalism rather than scientific verification. Nonetheless, climate change has become evident even to the laypeople: the disappearance of glaciers, the exacerbation of extreme weather events, the occurrence of arid conditions, and desertification phenomena are altering our way of life in such a way that the emphasis is now no longer on whether or not the climate change is human-induced but on how to stop it or adapt to its inevitable effects (European Green Deal 2019). Global warming is turning the Mediterranean and temperate zones into more arid regions, leading to the depletion of glaciers and rivers, increasing salinity in river basins, and impacting estuaries' biological systems; additionally, it is extending the duration of northern climatic summers and causing the melting of polar ice and having detrimental effects on lands and terrain (Dai et al. 2023; Hassani et al. 2021; Robinson et al. 2021; Scanes et al. 2020; Smith et al. 2023; Stranne et al. 2021; Surawy-Stepney et al. 2023; Tjiputra et al. 2023; Wallis et al. 2023). The warming trend has reached a critical point, affecting the very soils and terrains that sustain us all. It disrupts agricultural and water cycles, the biodiversity of natural systems, the production of fish and agriculture, and livestock rearing. It is systematically changing the structure of our entire food system, with measurable economic effects (de Winne and Peersman 2021; Hans-Werner 2011; Kotz et al. 2021, 2022; Ortiz-Bobea et al. 2021; van Ruijven et al. 2019).

Countering these adverse phenomena requires the creation of the right technical, practical, and economic conditions. We must share scientific and structural capacities in order to guide major social change, implement new solutions, and prepare the general population to accept a varying complex set of actions and change in habits (IPCC 2019; IPCC Working Group II 2022; IPCC Working Group III 2022).

Failing to stop climate change means creating conditions for new inequalities. It also means exposing us all to the risk of repeated massive food shortages for unpredictable periods of time. An unfortunate competition for food resources between rich and poor countries will expose millions of individuals, in particular millions of women and children, to socially fragile living in countries where the welfare infrastructure and economic capacities are less strong or completely absent.

Climatically warmer periods have existed before in human historical times, e.g., the so-called Medieval Warm Period—documented archaeologically, geologically, and historically (Crowley and Lowery 2000; Zalasiewicz et al. 2020)—which is considered a localized phenomenon (Neukom et al. 2019). It is well documented that the last 400,000 years have witnessed alternating glacial and interglacial periods known as Milankovitch cycles (Campisano 2012), the causes of which are attributed to a combination of astronomical phenomena and not to human activities.

The key difference now is the intensity of the current climate leap. The rate of change +0.15–0.20 Celsius degrees per decade (NASA Earth Observatory 2023) is rapid and frankly alarming (cf. Figure 1). While previously documented changes have occurred over hundreds of thousands of years, the current one is happening in less than a generation (cf. Figure 2). The correlation between the increase in GHGs concentrations and the onset of the era of industrialization is widely recognized (Hansen et al. 2010; NASA 2023).

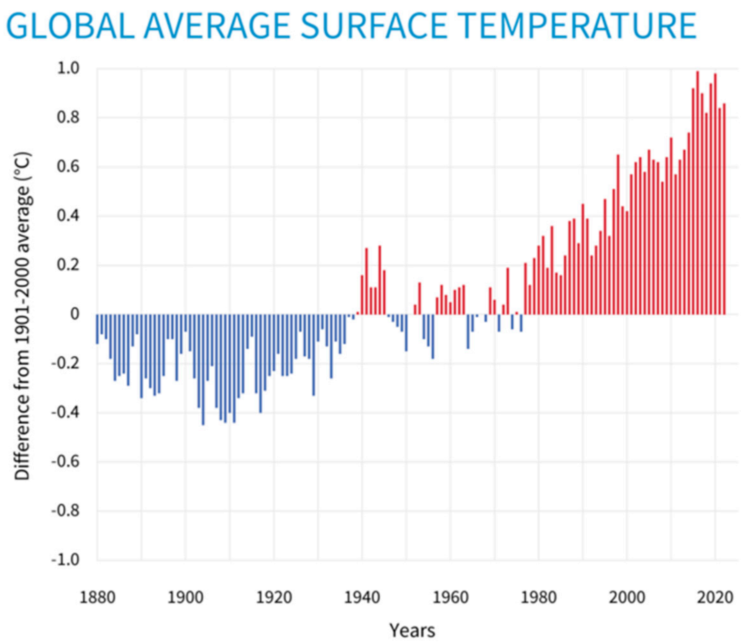

Figure 1. Annual surface temperature compared to the 20th century average from 1880 to 2022. The global mean temperature has increased by 1° Celsius above average. Blue bars indicate cooler−than−average, red bars warmer−than−average. (Source: Climate 2023; NCEI NOAA 2023).

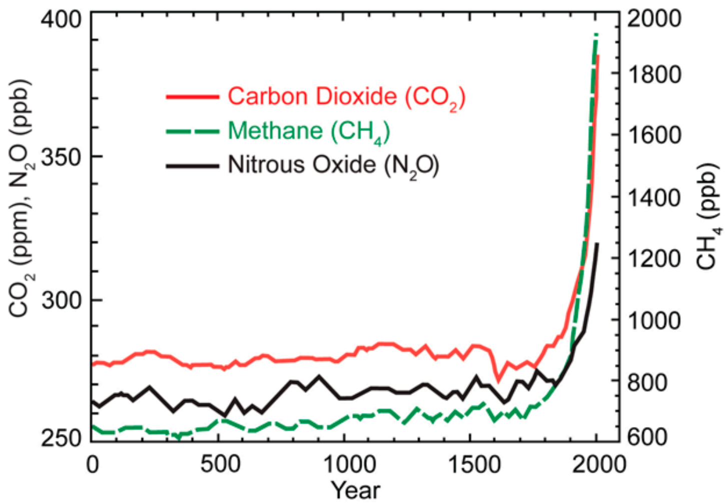

Figure 2. Atmospheric concentrations of relevant greenhouse gases over the last 2000 years. The major increase in greenhouse gases coincided with the beginning of the industrial era (circa the year 1750). Concentrations are expressed in parts per million (ppm) or parts per billion (ppb), indicating the number of molecules of the greenhouse gas per million or billion air molecules in an atmospheric sample (Source: IPCC 2007, chapter 2).

For decades, public perception has been skeptical and cynical about climate change, often considering it to be a slow and distant phenomenon (Burke 2013; Lewandowsky et al. 2013; Stamm et al. 2016). In reality, the phenomenon is becoming so intense and radical as to call into question our ability to effectively counteract these impending changes (National Center of Environmental Information 2021).

This article discusses an ongoing project operating in the cocoa sector in one countries, Côte d'Ivoire. On the one hand, Côte d'Ivoire is the world's largest producer of cocoa. On the other hand, it is also one of the African countries most responsible for deforestation in its territory, with significant ecological impacts.

The goal of the project is to sustain the socio-technical and ecological transition using low-cost technical approaches and to implement actual measures of social progress and inclusion. This is facilitated through a local agroecological school and laboratory directed by a Euro-African NGO (non-governmental organization) in Abidjan, the Communautè Abel.

Africa's ecological transition is critical to gaining control of global warming; any viable solution is complicated by the fact that we are acting within a globally relevant production chain, while also dealing with an economically undeveloped and socially complex area where social, cultural, and linguistic differences are present.

The Abidjan school of the Communautè Abel, attended by adolescents and women, with its 40-year presence in Côte d'Ivoire and its wealth of relationships with cocoa farmers, cooperatives, local authorities, village chiefs, and primary schools, is not only a tool of education but also an important social mediator and a means of instilling change and social acceptance.

We want to illustrate the difficulties and the inherent solutions of an approach that engages with a complex social reality and addresses both technical and social aspects of the ecological transition. We are going to describe how the interactions with NGOs (non-governmental organizations), agronomists, and local producers and the necessity of having a sustainable production chain led us to define a socio-technical framework and establish a living lab within the Abidjan school. This framework brings together social support, innovation, and ecological change (cf. Paragraphs 3.1, 3.2, 4.1, 4.2, 5.4, 5.5, 5.6). This article exposes these challenges, presents a multidisciplinary and multi-level perspective on the socio-technological transition (Geels 2002, 2004, 2005), and proposes a digital–social framework to support the transition.

After an introduction (Section 2) to general issues of global warming, territory, and social landscapes in Africa, we will focus (Section 3) on socio-cultural and socio-technical transition elements; we describe a pilot project that we consider as significant as a case study that encompasses agronomical, digital, and social perspectives. We will then proceed (Section 4) to expose the role of the women and address multilingual and multicultural questions. In Section 5, we expose the method of analysis and discuss the framework aimed at supporting the socio-technical transition. In Section 6, we conclude the article.

2. Territory and Social Landscape in Africa

The body that has been studying global climate phenomena for the longest time with authority is likely the UN IPCC (United Nations Intergovernmental Panel on Climate Change), which was established in 1988 by the WMO (World Meteorological Organization) and UNEP (United Nations Environment Program). The IPCC has the purpose of assessing the causes and impacts of human-induced climate change, suggesting solutions and calls for action (IPCC 2019; IPCC Working Group II 2022; IPCC Working Group III 2022).

Global warming is caused by the increased concentrations of GHGs (greenhouse gases), which change the equilibrium in radiative forcing (Shindell and Faluvegi 2009). Using clean energy is not the sole concern, especially not on a planet of 8 billion individuals (and growing) that need to be fed (Hans-Werner 2011). Farmlands, crops, livestock, and forests alone are responsible for emitting 23% of the human-created GHGs (IPCC 2019, p. 12). As a result of global warming, periods of drought and water scarcity, as well as sudden excesses of rainfall, have increased. Soil has become less productive, more exposed, with fewer plants, and reduced biodiversity, thus affecting production. To counter these challenges, farmers are resorting to using more and more chemical fertilizers, increasing the amount of greenhouse gases in the atmosphere. The reduction in vegetation and plants on the land diminishes the soil's ability to absorb carbon and decreases biodiversity, exacerbating the situation. This in turn causes more land degradation, intense rainfall, and extreme drought conditions in a downward spiral that will persist for decades to come.

2.1. Deforestation, Biodiversity and other Related Questions

Cocoa cultivation in Côte d'Ivoire is performed at the expense of Ivorian forests. Deforestation reduces biodiversity and the quantity of ecosystem engineers (EEs) species (Jones et al. 1994). EE species shape environments with cascading effects on other organisms, influencing ecosystem functions (EF).

Biodiversity conservation is crucial for sustaining the ecosystem and food system and is crucial for local economic and human health (Kilpatrick et al. 2017). De Groot and the Intergovernmental Science−Policy Platform on Biodiversity and Ecosystem Services (de Groot et al. 2002; IPBES 2019) identify ecosystems functions as including nutrient cycling (carbon, nitrogen, phosphorus, etc.), water dynamics (time and place of distribution of water resources), heat mitigation (presence and distribution of plants and forest), air regulation (oxygen production, carbon dioxide sequestration), information flows (indicator species) and disease control (intact biodiversity can limit the spread of diseases by providing natural barriers).

The objectives of an ecological transition study may include various aspects, such as conducting fundamental research to explore new hypotheses, conducting long-term survey programs for conservation purposes and management, engaging in applied research in conservation biology, or deploying and implementing strategies to address socio-environmental issues (Lindenmayer and Fischer 2013). Regardless of the specific goals, monitoring efforts are needed to determine changes in variables associated with environmental functions. This includes understanding how alterations in the environment are influenced by and related to changes in human actions with an impact on the socio-environmental system.

The non-linear relationships between ecosystem engineering (EE) and ecosystem functions (EF), along with the varying effects of co-existence, connectivity, and temporal autocorrelation, can influence the scale at which potential responses become detectable (Losapio et al. 2023). In the end, the determination of reasonable scales and the selection of appropriate explanatory and response variables is dependent on an understanding of the context and systems under study.

2.2. The Linguistic and Cultural Compass

Africa is a linguistically diverse continent with a rich tapestry of languages. An estimated 2000 different languages are spoken across Africa (Eberhard et al. 2023). However, the language of education, cultural interchange, and political power is often a foreign language, a legacy of a colonial past.

Language and multicultural issues arise in this context, where different ethnic groups interact and collaboration between European and African entities, associations, and researchers are at stake. Multicultural aspects are not always fully addressed in the context of ecological transition.

To counter these limitations, scholars and practitioners have started to integrate interdisciplinary perspectives that explicitly consider multicultural questions and power relations within sustainability initiatives. This involves engaging with fields such as postcolonial studies, feminist theory, and critical social science (Mbembe 2001; Mignolo and Escobar 2013; Mohanty 1988; Oyěwùmí 1997; Zeleza and Zeleza 2007) to provide a more comprehensive understanding of the complexities and challenges associated with sustainability transitions.

By incorporating multicultural perspectives and analyzing social and power relations, ecological sustainability initiatives can be better contextualized, more inclusive, and responsive to the diverse needs and aspirations of different social groups (Ibhawoh 2018; Mignolo 2011; van Noordwijk et al. 2020). These approaches can foster more equitable and sustainable outcomes and promote social justice in an ecological transition.

2.3. The Economic Impacts

Global warming has economic consequences that are reflected in productive output. Econometric studies have shown that climate change has reduced the TFP—the total factor productivity (Sickles and Zelenyuk 2019)—by approximately 21% since 1961, resulting in a slowdown that "corresponds to 7 fewer years of production growth" (cf. Figure 3). This effect is more severe "in the hottest regions such as Africa and Latin America" with "a reduction of about 26–34%" (Ortiz-Bobea et al. 2021). These include the major cocoa producers. The agricultural system has become more vulnerable and less resilient to changes. It is important to note that any increase in the global temperature over 1° Celsius degrees will have unfavorable effects on lives and the economy (IPCC Working Group II 2022).

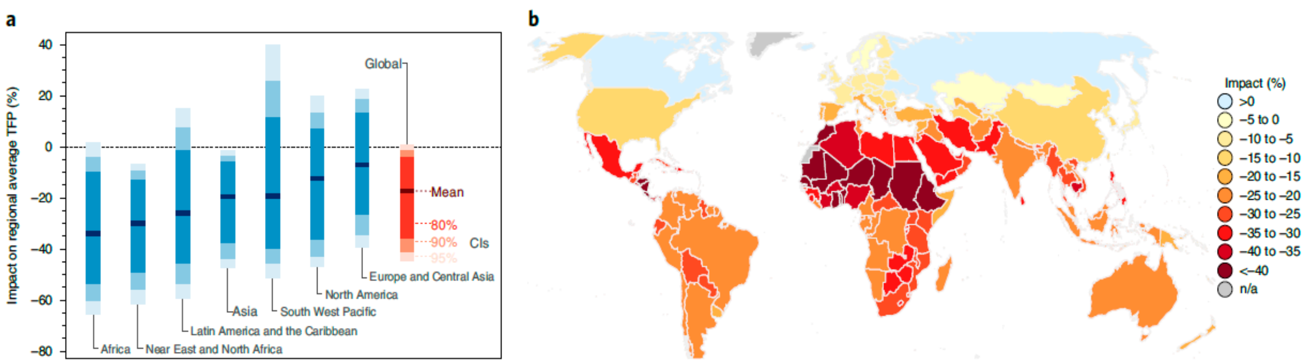

Figure 3. Global, regional, and country-level impacts of ACC. (**a**) Colored bands represent 95%, 90%, and 80% confidence intervals (CIs) that reflect climate uncertainty, econometric uncertainty, and specification uncertainty (from the choice of the econometric model). (**b**) The color in the map corresponds to the mean impact for each country. Source: (IPCC Working Group II 2022).

Countering these regimes requires a proper, equitable and sustainable use of the land and the monitoring and optimization of the food system and consumption chain. Any significant increment in the global temperature will have unfavorable and measurable social and economic effects (IPCC Working Group II 2022). In developing countries, this process can be complicated by limited resources, cultural impacts, local ethnographic contrasts, and political situations. Nevertheless, counter-actions must still be taken that have effects on agriculture, forestry and soils (IPCC Working Group III 2022).

3. Ecological and Socio-Cultural Transitions in the Cocoa Chain in Abidjan

Global warming is a problem that requires social understanding and practical action. It is fair to say that global warming is first a social and political problem—a problem of local and global policies—and is only a technological problem at a secondary level. Any transformation has social and economic costs, meaning that there are many forces opposing change.

The reports of the IPCC suggest several courses of actions (IPCC Working Group II 2022; IPCC Working Group III 2022). It is possible to act in the technological, digital, and agro-territorial sense (see paragraphs 3.1, 3.2, 4.1, 5.4–5.6). Social sciences, political forces, cultural and multicultural capacities must serve to bring about an understanding of the urgent need for change, and the magnitude and scope of the change required. We are in our infancy in terms of nature-based solutions and socio-technological actions in developing countries. It is not enough to act on the agricultural and food system at only the local level. It is also important to open up to the transnational and climatically diverse levels, both in order to capitalize on the experiences and knowledge transferred (researcher-to-researcher, policy maker-to-policy maker, farmer-to-farmer) by comparing different agro-ecological solutions and proposing methods and approaches that can be adapted easily. Owing to their flexibility and capacity to treat nonlinear, multifactorial problems, artificial intelligence and artificial neural networks can be the instruments of choice to classify, forecast, address and support a multilevel and multifactorial transition where dependent and independent variables have complex, nonlinear correlations.

Transition theory has gained attention across various disciplines with the goal of understanding the dynamics of socio-environment change (Smith et al. 2005; Wilson 2007). The term "transition" can be found in many different contexts: social class transitions (Chakrabarti and Cullenberg 2003), post-socialist transitions (Pickles and Smith 1998), biological evolutionary transitions (Zimmerer 2004), demographic transitions (Caldwell 2006), and sustainability transition (O'Riordan 2001). Bailey and Wilson (Bailey and Wilson 2009, p. 2327) argue that the diverse range of approaches to transition studies has led to a lack of coherence in defining what constitutes a "transition" study and has resulted in transition studies being seen as a quasi-theory, "lacking internal consistency or predictive capacity to form a coherent theory".

With this criticism in mind, our focus is on a specific segment of transition research known as socio-technical transitions. This field has increasingly influenced ecological studies on sustainability, and it is within this domain that we direct our attention.

3.1. The Socio-Technical Transition

Socio-technical transition theorists provide insights into the analysis of transitions, offering a framework to understand the dynamics, drivers, and barriers thereof. Lachman has reviewed the more notable transition frameworks (Lachman 2013).

The multi-level perspective (MLP) that was developed by Arie Rip and René Kemp (Rip and Kemp 1998) and further refined by Frank Geels and Johan Schot (Geels 2002, 2004, 2005; Geels and Schot 2007; Kemp et al. 1998) highlights the interactions and dynamics between three levels: niche innovations (emerging sustainable technologies or practices), socio-technical regimes (dominant systems and institutions), and broader socio-political landscapes. Geels' work in particular explores the barriers, drivers, and interactions that shape transitions and the role of agency, expectations, and institutional change (Geels 2018).

The SNM (strategic niche management) framework explores the role of niche innovations in transitions to sustainable systems. It emphasizes the importance of creating and nurturing protected spaces (niches) where alternative technologies, practices, and governance arrangements can develop and gain momentum, challenging the dominant technological regime (Kemp et al. 1998; Raven and Geels 2010; Schot and Geels 2008).

The TIS (technological innovation systems) framework examines the dynamics of innovation and diffusion within socio-technical systems. It explores the interactions between actors, networks, institutions, and knowledge in the development and deployment of technologies The TIS framework considers the alignment of technological, market, and societal aspects to facilitate transitions to sustainable systems (Bergek et al. 2008; Markard 2020).

Sustainable transitions are not only technological or economic in nature, but involve broader socio-economic, cultural, and institutional dimensions. The socio-technical transition theory, and in particular the works of Geels and their multi-level conceptualization, offers a description under a theory of how societies can transition toward more sustainable iterations (El Bilali 2019; Geels 2002; Geels and Schot 2007; Smith and Stirling 2010).

These frameworks can be used to shift the attention of researchers and practitioners away from artifacts or fixed socio-material patterns towards the coevolution of technology and society, emphasizing the dynamic interactions among social, political, and economic dimensions on multiple scales (see Figure 4).

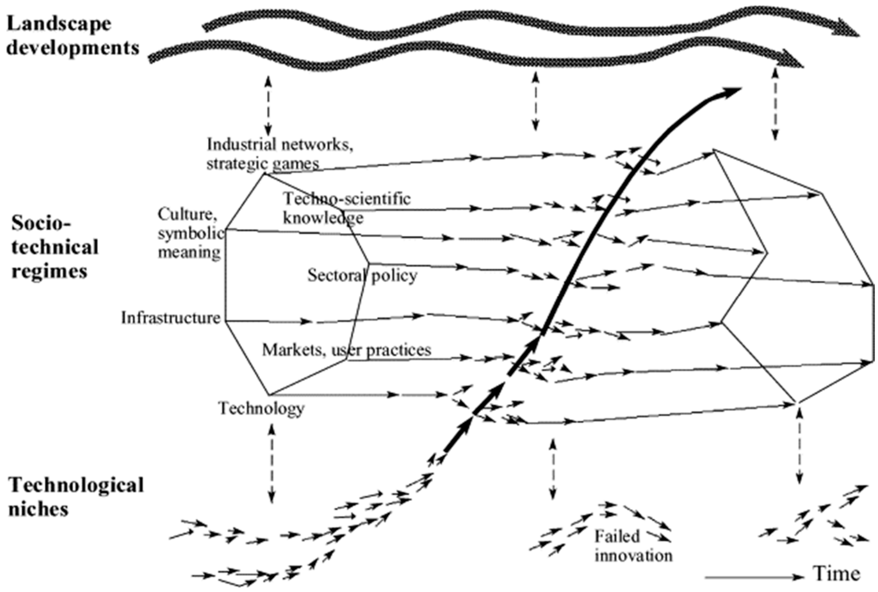

Figure 4. The multi-level perspective of socio-technical transitions. Source: (Geels 2002, p. 1263).

However, the potential of the socio-technical transition framework can only be realized if it is able to overcome several key critiques and become less elite and technologically focused, more sensitive to the role of spatio-social and data-analytical factors, and better able to account for the role that social interactions play in a multicultural situation in guiding or preventing transitions toward sustainable outcomes.

Our final and most fundamental concern, which builds on the above readings, is that socio-technical transition studies in general avoid addressing the issue of multiculturality and gender differences.

Ecological sustainability is becoming a core focus of socio-technological transition, linking fields like economy, agroecology, earth observation, sociology, and linguistics, but the strategies for achieving this goal remain in practical terms elusive.

While we refer the reader to the general literature addressing ecological ecosystem and socio-technological transition (Losapio et al. 2023; Sparrow et al. 2020), we posit that the latest advances in artificial intelligence for satellites, sensors, drones, mobile phone images, and the generative intelligence for natural language interaction, make it possible to monitor the drivers and obstacles involved in the transformation of socio-technical systems in flexible ways.

Digitalization, satellites, and sensors are means of change and instruments of monitoring. Artificial intelligence, convolutional neural networks, LSTM (long short-term memory), and RNN (recurrent neural network), with their proven abilities to understand (classify), explain (causal regression) and predict (forecast) with great flexibility, are probably the best tools to use to guide a process of agricultural and ecological transition (Anastasiou et al. 2018; Awad 2019; Matese and Di Gennaro 2018) in a way that takes into account the complex social and human variables present in a socio-technological approach (Bai et al. 2018; Hochreiter and Schmidhuber 1997; Kristiani et al. 2022; LeCun et al. 2015; Schmidhuber 2015; Song et al. 2018; Torres et al. 2021). Multilingual and linguistically flexible reporting tools based on generative intelligence (Bang et al. 2023; Liu et al. 2023; OpenAI 2023; Wu et al. 2016) can support and complement the human machine communication process.

3.2. The Abidjan Project

Climate change affects the four pillars of the food system: availability (production and yield), access (prices and ability to obtain food), utilization (nutrition and cooking), and stability (disruptions in availability). Risk management can improve the resilience of communities to extreme events that impact food systems.

The FAO (Food and Agriculture Organization of the United Nations) estimates a 60% increase in the need for food products and necessities compared to the 2005–2007 annual average. This relates to the projected growth of the world population to 9 billion individuals by 2050. The area under cultivation, globally, will increase negligibly, while a growing middle class, particularly in emerging economies, will increasingly demand a varied diet; consumers will demand better-quality and healthier products as their food awareness increases. Developing-country markets represent an opportunity for economic growth as growing local markets open up and demanding quality and flexibility of growth and production.

The project we illustrate is a pilot project located in Abidjan, the economic capital of Côte d'Ivoire and a city of nearly 5 million inhabitants situated on the sea, with a port, a lively city center and other urban facilities (see Figure 5). The surrounding area is largely, but not exclusively, devoted to the cultivation of the cocoa, with cashew nuts, rubber, and cotton among the best-selling products abroad; the country also produces palm oil, rice, and fruit, and these can be supplemented by crops compatible with the interests of European producers and farmers.

Figure 5. Abidjan, the economic capital of the Côte d'Ivoire, and its skyline (photo Wikipedia).

Côte d'Ivoire is a second-tier country among the developing countries with solid ties to France (French is the official language of the state) and has been growing economically since 1960.

The goal of the project is to support an agroecological school focused on (but not limited to) cocoa cultivation and teaching Ivorian women environmentally sustainable farming and processing methods, one which is supplemented and aided by digital intelligence and resilient agroecological farming methods.

The first goal is to increase output by decreasing input to and reduce carbon footprint. However, this is not the only question. One important fact is to help in the reduction of deforestation. Trees protect the soil, reduce desertification and dry-outs, and absorb carbon dioxide.

Locals tend to destroy forests to acquire lands for the production there is not such a thing like a "land registry" in many parts of Africa, and in Côte d'Ivoire this is no different, the land is owned by the person who cultivates it. When needed, local peasants take down a piece of forestry, which is considered to be "of everyone and of anyone", and begin a new cultivation. This method is quite accepted, and this approach is not discouraged by the authorities. Monitoring the soil and lands requires the use of smart plantation monitoring tools such as soil sensors, drones, and satellites image, combined with methods of intelligent analysis and prediction.

The second goal is to change production and teach the locals how to transform the raw crop into a product ready to be sold, while respecting the local capacities and farming traditions. It is also important to start a process of including women in the production chain in order to free them from their economic dependence.

The third aim is to ensure the ecological process is accepted, comprehended, and "absorbed" by the involved population.

Cohering these three questions into one with an unified goal and a shared and accepted comprehension of the problems and ecological necessities requires a shared approach, a step-by-step agro-ecological methodology that pays attention to the local cultural questions.

We use a living labs approach, involving a shared space within a school where new cultivation methods can be learned, new technologies can be used, and shared decisions can be made. Living labs ensure social acceptability of ideas, promote a conscious transition, and create relationships between farmers and entrepreneurs. A living lab also has the advantage of creating textual data complemented by written and oral communication and reports. These communications are usually in French.

At the University of Turin, the figures among the Department of Foreign Languages and Literature and Modern Cultures, the Agronomy Department and the Computer Science Department are involved in different capacities in this project.

One of the goals of the agroecological school is to ensure the attainment of economic independence for its students: it gives hands-on education, providing training in new methods of cocoa cultivation and cocoa processing for local markets.

These activities take place:

- Partly in the atelier (workshop) in Gran Bassam (Abidjan) already in operation and under the responsibility of the Ivorian Communauté Abel linked to the Gruppo Abele Foundation in Turin, Italy, (www.gruppoabele.org accessed on 29 June 2023), a well-known and respected Italian pro bono philanthropic institution. The NGO Communauté Abel has been in Côte d'Ivoire for more than 40 years and has a strong set of local relations, ensuring contacts and the acceptance of project activity;
- Partly in the school being established by Communauté Abel in Abidjan, which will be expanded through this project into an agroecological school;
- On farmland provided for the living lab Agrimagni, an Ivorian company with pro bono purposes, founded 12 years ago by an entrepreneur from Pavia, Italy, with philanthropic aims.

There is a documented relationship between women's education and GDP growth in developing countries (Knowles et al. 2002; Mammen and Paxson 2000): women create safe and economically stable businesses and pass on their capacities, assets, and activities to their offspring by establishing principles of a lasting economy and business stability. The overall purpose of the NGO Communauté Abel in Abidjan and the Gruppo Abele Foundation of Turin is the social and economic rehabilitation of socially fragile women and minors at risk of trafficking and exploitation.

In this context, there is an Ivorian agricultural supply chain for cocoa farming connected to the NGO. Made up of small farmers and entrepreneurs, this is known as the

Chochofair organization (Chochofair 2023) and gives the opportunity to develop business relationships between African farmers and Europeans companies that are part of the project and those that will join in the future.

The school, thanks to the project, will be able to create entrepreneurial activities of self-employed workers, women small entrepreneurs, and employees who can start small self-employed businesses. The pilot project, after a period of activity, data collection, and assessment in Côte d'Ivoire, has become a candidate to be replicated in other regions with which the NGO is already in contact in order to initiate other collaborations in the Republic of Togo, São Tomé e Príncipe, in Madagascar.

The intelligent methods of monitoring can be reapplied with minor modifications and adaptations in countries situated in similar climate zones (between +20 and −20 degrees of latitude), and the living lab approach can be recreated to foster the emergence of social dimensions.

Specifically, the goals of the agro-ecological school are to develop a just transition transformative approach to:

- Reinforce sustainable agricultural practices;
- Improve the well-being of the natural ecosystems;
- Improve the well-being of communities and people;
- Integrate production practices and cultures with social and multicultural interventions;
- Empower women.

This requires interdisciplinary actions that ensure:

- Monitoring crop health;
- Decreasing deforestation;
- Increasing soil protection;
- Increasing biological diversity;
- Increased water care;
- Preference for non-chemical fertilizers;
- Identification and reduction of dry areas.

These actions were performed while paying attention to efforts to boost social cohesion and labor equality, while incrementally elevating gender equality and improving women economic independence. In short, they serve to ensure a just transition process.

The practical means of interaction happens in the context of an Ivorian agro-ecological school, using a living lab approach to ensure a multifactorial and multilevel approach to transition.

4. The Socio-Multicultural Question and Relevance of Women in the Abidjan Project

An emphasis that the project wants to pursue in Abidjan is the protection and empowerment of African women, the recognition of their equal role in society, and the promotion of their economic independence through the development of practical and productive skills.

The long-term effects of focusing on women's education are stymied by an African proverb that states: "If we educate a boy, we educate one person. If we educate a girl, we educate a family—and a whole nation" (African proverb attributed to various sources including Dr J.E. Kwegyir−Aggrey, and quoted by James Wolfensohn, President of the World Bank, 1995).

This adage not only reflects local beliefs (whose value may be culturally relative), but finds confirmation in research (King and Hill 1993; Knowles et al. 2002; Mammen and Paxson 2000; Psacharopoulos 1994). The African proverb emphasizes the crucial role that women play in society, not only as individuals but as leaders and agents of change. When women are empowered through education and skills development, they can make substantial contributions to their families, communities, and the nation as a whole.

Investing in women's education has long-term effects that go beyond the individual. It leads to increased economic growth, reduced poverty, improved health outcomes, and greater political participation. Educated women are more likely to secure higher-paying jobs, start businesses, and contribute to the overall economic development of their countries. Moreover, educated women are better equipped to make informed decisions about their health, well-being, and that of their families. Educated women are more likely to have smaller families, participate in the workforce, and have higher incomes, which in turn helps to lift their families out of poverty. They are also more likely to invest in their children's education, leading to better outcomes for future generations.

Furthermore, when women are educated, they are more likely to be engaged in political and civic life, which can lead to greater gender equality and increased representation of women in positions of power and influence. Overall, investing in women's education is not only the right thing to do from a social and moral perspective, but it is also a sound economic and political strategy that benefits society as a whole.

4.1. The Multilingual and Multicultural Question

Western perspectives and languages have dominated various scientific fields, and this includes sustainability science. As a result, the representation and involvement of non-Western nations and communities, such as those in Africa, has been insufficient (Sénit and Biermann 2021). Sustainability science "does not speak" the over 2000 languages of Africa, that is, it has not yet fully integrated Africa's diverse linguistic and cultural contexts.

This may hinder efforts to implement the Sustainable Development Goals (SDGs) on the continent. This is compounded by the fact that the language of education and training in Africa is often a foreign language, a legacy of the colonial period, and by the marginalization and neglect of local languages. The lack of indigenous terminology can make it difficult for local communities to engage with sustainability concepts, as these concepts may not align with their cultural and linguistic views (Litre et al. 2022).

Many African languages are localized and specific to their regions. By collaborating across disciplinary boundaries, researchers can develop more culturally and linguistically sensitive approaches to sustainable development that account for the diversity of African languages and cultures. For example, generative intelligence can be used to develop machine translation systems that accurately translate sustainability concepts into local languages (Bang et al. 2023; Liu et al. 2023; OpenAI 2023; Wu et al. 2016), while sociolinguistics can help to identify and address cultural and linguistic barriers to effective communication about sustainability (Baumgarten et al. 2008; Fan et al. 2020; Lample and Conneau 2019).

The language barrier needs to be considered. People who are not fluent in a particular language may struggle to express themselves clearly or be limited in the range of vocabulary they can use to convey their thoughts and ideas. Additionally, cultural differences can play a role in how people may or may not accept specific aspects as certain concepts or ideas may be expressed linguistically in different ways and be accepted differently in different cultures. This can lead to misunderstandings and miscommunications, especially in cross-cultural interactions. Overall, linguistic and cultural barriers can have a significant impact on effective communication and acceptance. It is important to be aware of these barriers in order to minimize their impact and promote inclusion.

Examples of linguistic barriers include:

- Language differences: variations in regional dialects, accents, and slang.
- Limited vocabulary: individuals who speak a non-native language may have a restricted range of vocabulary, making it challenging for them to express themselves clearly and accurately. This can lead to misunderstandings and miscommunication.
- Grammatical and syntactical differences: variations in grammar and sentence structure can create confusion and misunderstandings.
- Cultural differences: different cultures may have distinct norms regarding addressing people, expressing emotions, and using nonverbal communication, which can create significant barriers to effective communication.

- Technical language: specialized terminology can create linguistic barriers as individuals who are not familiar with such language may struggle to understand the meaning of a conversation or written text.

The significant impact of these linguistic and cultural barriers can lead to consequences such as reduced access to education and a limited availability of necessary services. Recognizing these barriers and taking appropriate measures to address them is crucial.

These measures encompass a range of actions to address cultural barriers and promote effective communication across languages. They include advocating for multilingualism, developing policies that embrace diversity, providing language training in specific contexts, implementing literacy courses, empowering women in their social contexts, and utilizing generative intelligence technology to enhance cross-lingual communication.

Advocating for multilingualism recognizes the value of maintaining and promoting multiple languages, fostering inclusivity, and encouraging language preservation. This can be achieved through public awareness campaigns and educational initiatives that promote the importance of linguistic diversity.

Creating policies that support linguistic diversity involves establishing frameworks that respect and protect the rights of individuals to use their native languages (May 2005; Piller 2016). These policies can encompass language-inclusive education, official language recognition, and language access in public services (Amuzu 2019; Banda and Mwanza 2017; Blommaert 2007; Frekko 2008; Oyeniran 2017; Tollefson 2002).

Offering language training in certain circumstances recognizes the need for language acquisition to bridge communication gaps. This can include language courses, language support in the working environments, or training programs for individuals working in diverse linguistic contexts. Implementing literacy courses addresses the foundational skill of reading and writing. Literacy programs can help individuals to overcome language barriers, improve their ability to express themselves, and access opportunities for education and employment (Bunyi and Schroeder 2017; Lewin 2009; Quist 1994; UNESCO 2019).

Women's social empowerment also acknowledges the importance of gender equality in language and communication domains. It emphasizes inclusion by enabling their active participation and presence in social and labor domains, thus strengthening gender equality and emancipation (Amadiume 1987; Holmes and Meyerhoff 2003; Kiptot 2015; Tripp 2015).

The use of generative intelligence technologies, such as the latest machine translation models, enhances cross-linguistic communication (Lample and Conneau 2019; Liu et al. 2023; Wu et al. 2016). These tools facilitate real-time translation, refine cross-cultural collaboration and mutual understanding, and bridge the gap created by language barriers (Bahdanau et al. 2014; Luong et al. 2015; Vaswani et al. 2017).

4.2. The Living Lab Approach

Central to the project in Côte d'Ivoire is the living lab. A living lab is a user-centered approach to innovation activity where research and everyday practice are integrated in a partnership of different types of actors, both public and private entities (Almirall and Wareham 2011; Bilgram et al. 2008). The purpose is to arrive at systematic developments of shared solutions and innovation. Living labs enable the process of exploring, testing and evaluating ideas, concepts and technological artifacts in real use cases in a shared environment (see Figure 6). Being hosted in a school, it becomes the natural mediator among people of different extraction and different cultural backgrounds, enabling participants to voice different opinions in different languages to arrive at common outcomes.

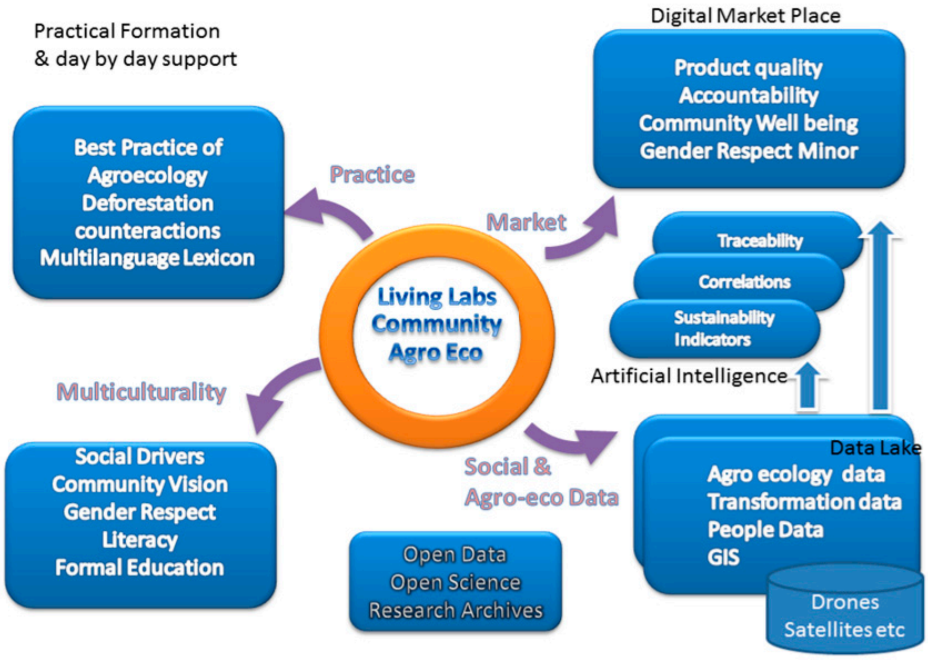

Figure 6. The Abidjan cocoa project: the living lab and its scopes.

The living lab also serves to break some project barriers. Some solutions may be produced in silos, with each expert working in their own area. In practice, innovators only come to merge their "solutions" at the end of the project, i.e., "a posteriori" (Musch and Streit 2019). The living lab approach has the advantage of setting and pursuing a process of continuous exchange between innovators, territory, people and social change experts from "day one".

The living lab is hosted by the agroecological school and aims to:

- Defend the soil, control vegetation status, monitor biodiversity, and mitigate the negative impacts on crop growth caused by disease and environmental threats;
- Increase control over the hydrological situations (e.g., mapping water resources and forecasting groundwater location, quantity, and quality in terms of pollutants);
- Promote biodiversity by leveraging local agronomic knowledge and implementing agroecological approaches, with consequent reduction of deforestation activities, and chemical fertilizers;
- Conduct in situ monitoring of agricultural production, correlating the production with relevant indicators;
- Ensure a correct understanding of resources to monitor the health of lands and crops as well as forecasting water situations;
- Foster purposeful and informed knowledge of ongoing ecological and economic processes, encouraging dialogue and shared decision making. This includes blending technical approaches with decision-making processes to address root causes, policy issues, and social obstacles;
- Pursue a transition that is multicultural and gender-inclusive.

This requires shared and coordinated actions among companies, NGOs, local farmers, and researchers in an integrated innovation process to test new agronomic solutions, using a participatory approach to ensure a better understanding of systemic problems and their root causes in order to find shared solutions.

The overall goal is to achieve an equitable transformation process that leverages interdisciplinary actions to decrease the carbon footprint and realize the principles of solidarity and growth enunciated by the Sustainable Development Goals (SDGs) 1—4—5—8—10—11—13—17 integrated into a multifactorial and multilevel life-cycle social sustainable assessment (LCSSA).

5. Technological Aspects

In this section, we provide a succinct overview of the technological elements incorporated in the project, as well as the key aspects to comprehending the techno-digital components of the project.

5.1. Vegetation Index

Plants exhibit a unique way of reflecting electromagnetic radiation. The reflectance of vegetation is typically low in the blue and red regions of the electromagnetic spectrum, moderately higher in the green region, and the highest in the near-infra-red range. This is caused by the strata and their distinct absorption patterns across the spectrum. The combination of low visible reflectance and high near-infrared reflectance is unique for most vegetation types and that is why it is known as the vegetation spectral signature. A vegetation index (VI), such as the NDVI (normalized difference vegetation index), defines the vitality and photosynthetic activity of plants (see Figure 7). There are numerous VIs and every vegetation index can serve different purposes (IDB Index Database 2023). Proximal image data analysis (drones) and remote data analysis (satellites) can be used to monitor crop status, foliage and plant conditions, and also to assess ecological responses to environmental changes (Asner et al. 2004; Pettorelli et al. 2005).

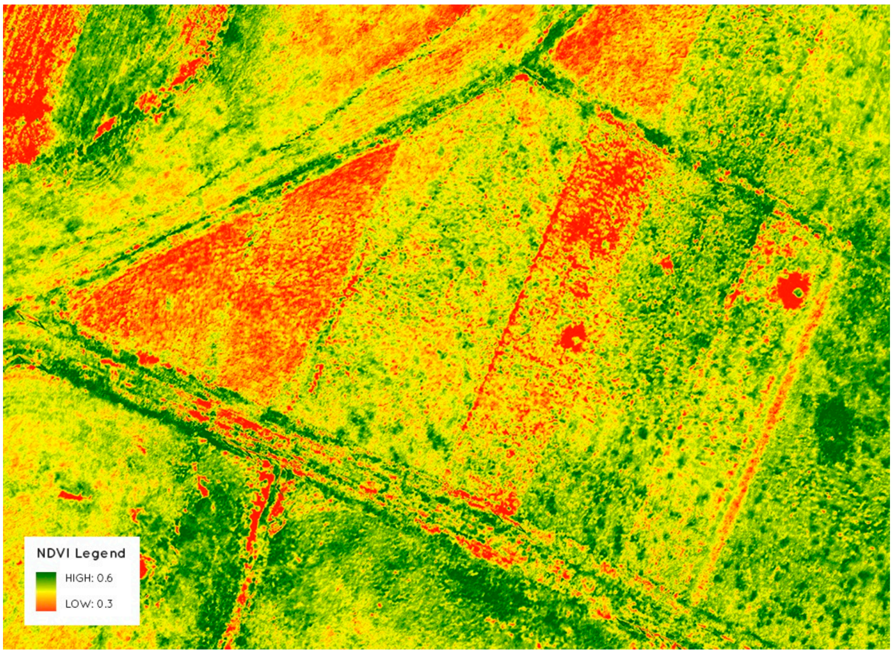

Figure 7. NDVI index used to identify areas with more or less vegetation. The red pixels identify soil that is not covered by crops or vegetation. (Source: https://www.precisionhawk.com accessed on 29 June 2023).

The NDVI images (normalized difference vegetation index) obtained from satellites data around Abidjan are used to find the species of interest (cocoa) and to identify other features such as forest, soil, and water. The results are validated with other sources such as satellites data from the GRACE mission (Gravity Recovery and Climate Experiment) and the ERA5 database (ERA5 is a climate reanalysis dataset).

The goal is to detect ten "conditional classes":

- Mature cocoa;
- Young cocoa;
- Unhealthy cocoa;
- Crops;
- Forest;

- Bare soil;
- Water bodies;
- Clouds or shadows;
- Dry areas;
- Other surfaces (or data not interpretable).

By analyzing changes in NDVI images over time, it is possible to assess environmental changes, monitor vegetation health, detect shifts in vegetation patterns and dynamics, track phenological cycles, identify land cover changes, and evaluate the impacts of these developments on ecosystems.

Besides NDVI, other VI indexes under scrutiny are: enhanced vegetation index (EVI), soil-adjusted vegetation index (SAVI), green normalized difference vegetation index (GNDVI), normalized difference red edge (NDRE), chlorophyll index (CI), leaf area index (LAI), and photochemical reflectance index (PRI).

5.2. Soil Sensors

Soil is another important source of information in land management. Information can be gathered from soil conditions, indicating the lack or abundance of substances needed for growth and the conditions that may or may not make crops healthy. Depending on economic possibilities, the farmer can periodically sample the terrain in specific sites and give samples to a local specialized laboratory to obtain useful data. Another possible low-cost approach is to place sensors in the terrain, near the roots (rhizosphere) or between the plants, in order to obtain useful data on the soil situation.

Sensors comes with some advantages:

- Continuous monitoring: a limited number of soil samples does not produce an accurate representation of soil properties (throughout the area). Sensors provide a more accurate assessment of soil properties needed to successfully implement site-specific management decisions;
- Simplicity of use: no lab samples, delays, around-the-clock sampling;
- Adapt to small solutions and lab experiments: e.g., to evaluate a baseline;

However, this approach has its disadvantages too:

- Density and costs: not suitable for large extension of crops;
- Network an energy: an infrastructure must be present for networking and routing and requires energy sources (note: method of sensing "on the go" do not require energy sources and network management).

5.3. Precision Agriculture or Agroecology?

Land is simultaneously a source and sink for several greenhouse gases (GHGs), with fluxes influenced by both natural and anthropogenic processes. There are three primary causes:

- The direct effects of anthropogenic activity due to change in land cover and land management;
- The indirect effects of anthropogenic environmental change, such as climate change, carbon dioxide (CO_2), fertilization, and nitrogen deposition;
- Natural climate variability and natural disturbances (e.g., wildfires, windrow, and disease).

When it comes to ecological transition and environmental adaptation in agriculture, there are two main competitive philosophies to consider:

- Precision agriculture, a system which makes extensive use of targeted and intelligent technologies, soil sensors, drones, satellite imagery tractors and planting machines equipped with GPS, and closed feedback machines for harvesting and crop selection. These are integrated systems that have the capability to utilize and enhance intelligent soil analysis and to perform forecasts or regressions based on the analyzed data (Anastasiou et al. 2018; Awad 2019; Matese and Di Gennaro 2018). The general

principle is defined by (Pierce and Nowak 1999) "a system that provides the right tools, in the right place, at the right time," where "right" is defined as a technical agronomic intervention. The general idea is to maximize efficiency by decreasing the input: practitioners should follow the cost−benefit analysis of ROI (return on investment) (Duncan et al. 2021), social impacts are not at the center of the process.
- Agroecology, a system which sees the gradual and natural integration of production into the environment and aims to increase biodiversity, the protection of the water cycle, supplement forest and agricultural production, and—this is not marginal—respect for local customs and traditions and cultures (Dalgaard et al. 2003; Pretty 2008; Wezel et al. 2020). Even in Europe, PGI (protected geographical indication) and high-quality PDO (protected designation of origin) products depend on a historical and secular relationship existing between the food system and local traditions and cultures, which cannot be separated one from the other without "pain", i.e., without a loss in quality, and a counter-reaction in terms of market acceptance and revenues.

Agroecological science encompasses different areas of the agrifood system such as agricultural social networks, food markets, public food procurement, and consumer−producer relations (Dalgaard et al. 2003).

Although there is much discussion on which approach is the most appropriate, there is no need to think of a clear digital−technical separation between these methods; they are at two extremes, but can work to partly complement each other in daily practice in specific situations. Our concern is not in identifying the digital methodology to be used but how the transformation can take into account the social dimensionalities that may influence development.

5.4. Machine Learning, Satellites and Sensors

Earth sensors, satellite information, meteorological data, and machine learning methods using CNN (convolutional neural networks), LSTM (long short-term memory networks), transformers (self-attention), and RNN (recurrent neural network) are all methods within the field of deep learning that can derive and detect dependencies in data and generate classification, detection, regression or forecasting models (see Bai et al. 2018; IDB Index Database 2023; Hochreiter and Schmidhuber 1997; LeCun et al. 2015; Kristiani et al. 2022; Schmidhuber 2015; Song et al. 2018; Torres et al. 2021). They can provide information on the evolution of cultivation, droughts, water shortage, the presence of underground water, soil intervention points and plant diseases, and also forecast climatic crisis with increasing accuracy.

In this phase, we are employing two concurring methods: RNN for classifying healthy and unhealthy cocoa pods and plants (based on close-up images), and CNN and LSTM (Copernicus-2, GRACE and ERA5 databases) for assessing conditions on the terrain (deforestation, dry areas, healthy/unhealthy crops), and predicting underground water availability, dry periods, and extreme conditions at a regional level.

To save costs, our approach involves developing and testing our models for monitoring soil and crop quality in specific territories, by correlating meteorological aerial values (ERA5) with satellite images (Copernicus-2), hydrologic information (GRACE) and NDVI data (Copernicus-2), so that a digital twin model becomes available.

The digital twin can later be employed in other situations and contexts where farmers or researchers do not have the time or the resources to install new monitoring sensors or retrain the neural models. Instead, they can rely on the previously developed digital twin to simulate the overall behavior of relevant variables or to classify, explain or predict situations (e.g., underground waters conditions or the health status of vegetation).

These simulations can support ecosystem design, provide valuable insights into territories, or give indications on actions to increase fertility and reduce impacts in terms of GHGs. They can also answer questions by running data-driven tests on observed variables, confirming or excluding hypotheses.

Examples are the use of χ^2 tests, i.e., the extraction of Bayesian networks (Drury et al. 2017; Yet et al. 2016, 2020) to reveal the effect−cause relationships among variables and at the same time exclude connections among the statistical independent ones.

We implement explainable artificial intelligence/machine learning (XAI/XML) (Hoxhallari et al. 2022; Linaza et al. 2022; Tsakiridis et al. 2020) approaches to clarify the influence of variables on prediction models, extract post hoc considerations and provide counterfactual explanations. This data exploration and what-if analysis deepens the causal relationships between variables, enabling better informed decisions and a more cautious utilization of the resources (Chum-Im et al. 2021; Krizhevsky et al. 2017; Măruşter and van Beest 2009; Shahi et al. 2022). This is especially valuable if these resources are scarce or shared by a community, and if the consequences of the researchers' and farmers' choices fall on their future.

The project uses open-source software and low-cost sensors, as well as open access data (Copernicus-2, GRACE, ERA5). Additionally, close images taken by farmers with their mobile phones are utilized. Our method of classification and forecasting are open-source solutions, making their cost virtually null. Low-cost sensors for measuring gas-phase air pollutants and soil chemical are among the most affordable self-building technologies usable, even in small-scale environments. This approach is specifically designed to address the issue of digital costs, which is particularly relevant when working in developing countries.

5.5. The Decision Support System

Many activities need to be secured to enable an approach that combines environmental data, field data, management and social data for the decisions to be made.

Data for field monitoring are collected by using satellites and data repositories, and leaf, pods, or canopy images can be captured manually (mobile phones) or using drones (the choice depending on technological availability and costs). Additionally, textual data from reports and written records reflecting management and social issues are incorporated into the information system (see Figure 8).

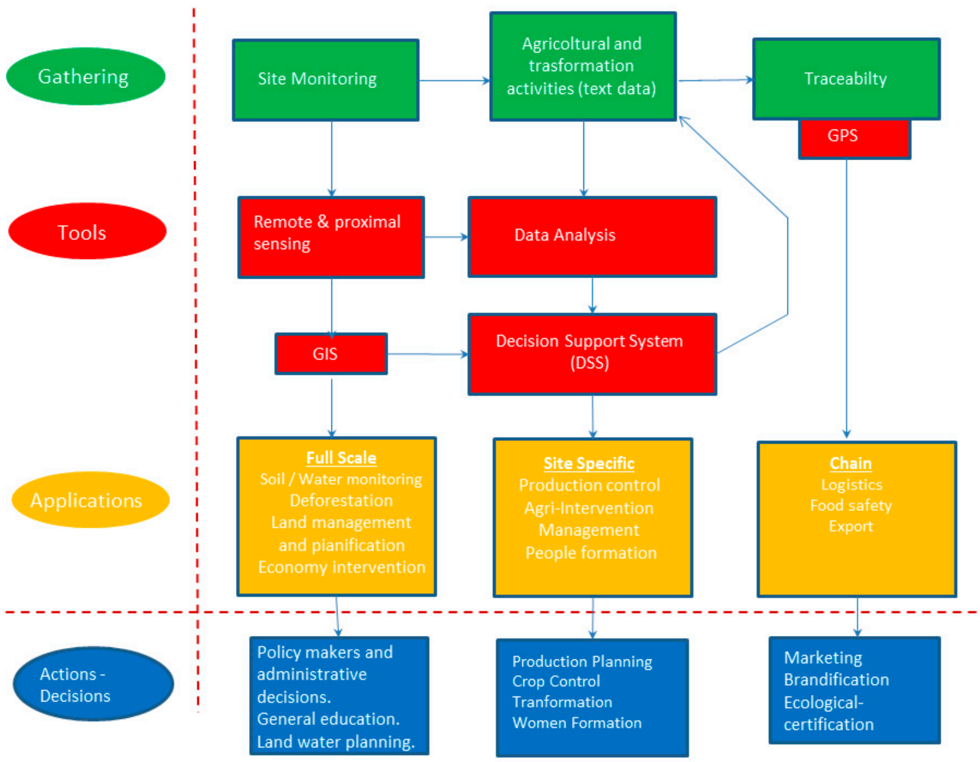

Figure 8. Data analysis schema and actions/decisions scopes.

These data (satellite-sourced, proximal, social, cultural and those related to land state and production) are fed into a classifier for a "first-breath" analysis that is piped into the further levels to serve as a decision-making tool.

It is important, therefore, that the neural network be constructed with characteristics that highlight the relationship between indicators, analytical vegetation indicators, and the quality measure of the analysis under differential conditions (specific season, young plantations, late-stage plantations, presence of forest, underground waters, uncovered soil).

In fact, these data must be used as inputs to a partially automated decision support system. Still, it is important to provide local growers and experts with ample leeway at these stages in order to avoid the rejection of the solution as a tool because it is perceived as too invasive in terms of decision making.

Satellite data are associated with specific locations (GIS, Geo Information System). At the same time, measures are taken to ensure traceability and enhance the product in terms of brand recognition, quality, origin, and ecological certification. Our product, marked with a tracer such as a QR code, provides evidence of being environmentally friendly, respecting gender, and being produced in Côte d'Ivoire.

The tools used at the broader regional or provincial level provide policymakers and local administrators with information about what is happening in their areas. This enables them to present objective data and educate farmers on agroecological interventions and environmentally friendly farming methods.

At the site-specific level, the data will provide indications of where further interventions are needed, and what results have been achieved (see Figure 9). These data also complement staff training actions, providing feedback on what is happening in the living lab and the effects of the actions taken.

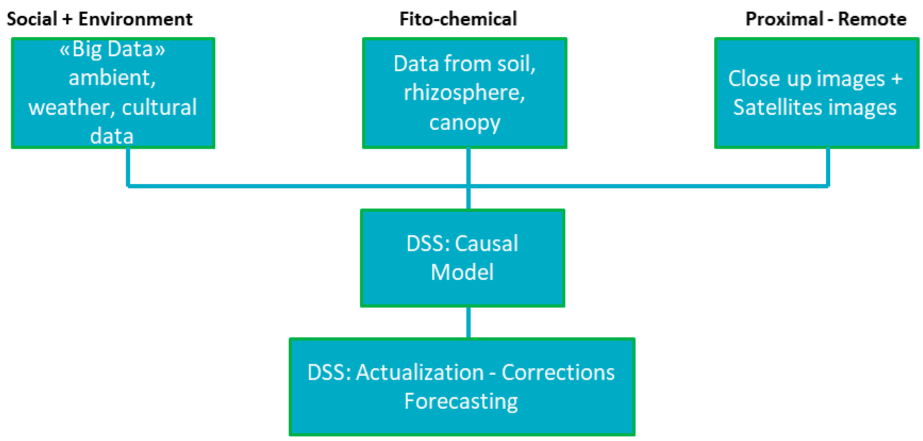

Figure 9. There are three types of data sources: text data, soil data, and image data. These can differently serve to create a causal model of a decision support system (DSS).

5.6. What to Measure and What to Support

A threshold approach is used to monitor the state with respect to macrovariables. A threshold approach has pros and cons, the main advantage being simplicity of use and easiness of understanding. Supervised causes may exhibit multilinear relations with DSS state variables under examination, but neural networks are capable of responding to complex multilinear phenomena to transform them into linear or scalar output values (label). This assists in the decision-making process based on thresholds.

Ecological thresholds refer to points or levels at which ecosystems undergo significant changes in response to gradual or abrupt shifts. They are used to describe the nonlinear and persistent reorganization of ecosystem properties (e.g., state variables) in response to gradual or discrete changes in social or environmental patterns and drivers (Groffman et al. 2006; Zhang et al. 2018).

The preference for a threshold approach is based on two considerations. First, in many processes of production, managers often consider decisions with thresholds in mind. By adopting a threshold approach, decision makers can effectively address critical points in ecosystem functioning and management. Second, the use of thresholds compels people to consider a broader array of ecosystem and social behaviors and attributes when evaluating the status of the ecosystem (Morris and Doak 2002; Tongway and Hindley 2004).

By acknowledging ecological thresholds and integrating them into decision-making processes, managers and researchers can gain valuable insights into ecosystem dynamics, anticipate potential tipping points, and implement timely and effective measures to maintain or restore ecosystem health and functionality. In addition, the use of state macrovariables, defined by thresholds, can be used to prioritize management and restoration efforts in management areas that may encompass tens of thousands of hectares (Suding et al. 2004).

On the other hand, an uncritical use of thresholds may lead to the abandonment of efforts in areas that would otherwise benefit from intervention if not reflected in threshold definitions.

5.7. State Variables

Variables of interest are defined by opposing criteria: criteria that contribute positively to change and opposing criteria. We defined categorical variables because they clear and easy to comprehend as good, acceptable (still good but to be monitored; otherwise barely acceptable but improving), or negative. The three values are ranges for each state variable (see below) where good obviously means that actions are going in the correct direction for the realization of social, or ecological, or technical, political, and educational change according to one's measure. The meaning of negative is obvious. If the variable being monitored is, e.g., an educational activity, such as the implementation of a course, an unacceptably low percentage of women is a "negative" value. Any situation falling between the extremes indicates an acceptable evolving state. However, the difference lies in the assessment of the differential value from the past. If the value falls below the "good" threshold, this should be monitored, and action should be taken to return it within "safe limits". Conversely, if the value exceeds the negative threshold and enters the acceptable zone, it improves but is still to be kept under observation.

So, as a result, we have a decision support system (DSS) with independent variables derived from the data sources, and dependent variables (the state variables) utilized to support decisions.

The independent variables under scrutiny are:

- Technological
- Positive: research and development achievements, software development, technical instrument in operation, and ability to use tools.
- Negative: technical failures, infrastructure disruption, and accumulation of negative externalities.
- Ecological
- Positive: density of plants on an area, growth of crop, health of cultivation, quantity of coca beans harvested, and increased biodiversity.
- Negative: deforestation, drought, shade-free soils; crop-specific diseases, drastic changes in rainfall, worsening weather conditions, and decrease in biodiversity.
- Political and Social
- Positive: growing support coalitions and constituencies, improvement in available skills, increase in funding, increase in financial capacity, and policy changes that support the niche innovation (subsidies and supportive regulations).
- Negative: clout disagreement and fracturing of social networks (defection of key social groups or people from the main scene of action—in this phase, the living lab and the school) eroding the influence of the change process, with supportive policies being removed or disruptive policies being introduced.

- Social and Cultural:
- Positive: discourses and visions that attract attention, cultural enthusiasm, increase of socio-political legitimacy, empowerment of African cultures, increased social diversity of groups, and increased percentage of women participating in the change process.
- Negative: cultural discourses undermining the legitimacy of the present actions and course change, negative discourses and fights among people from different backgrounds and cultures; difficulties in women's access in learning processes and activities; and negative perception of the presence of women.
- Agroecological School: i.e., the success of the school in its socio-ecological actions and as an educational tool.
- Positive: number of students trained, number of eco-oriented courses, percentage of women participants, number of days devoted to training, positive feedback from students, percentage of women literate, and positive perception of women's presence in learning activities.
- Negative: the same dimensions but in negative directions.

The state variables, which are nonlinear dependent variables in the decision support system (DSS), are intended to support decision-making and guide corrective actions. They cover the following areas:

- *Sustainable Resources*: Thresholds provide guidance for sustainable resource management. They help to determine limits for activities such as deforestation, or unnecessary excesses of inputs (water, fertilizers), and to prevent the overexploitation or degradation of land and water resources. By setting thresholds, the specific actors (NGO, farmer, and researcher) can ensure that resource use remains within sustainable limits and thus avoid irreversible damage to ecosystems;
- *Ecosystem Restoration and Conservation*: These variables play a crucial role in ecosystem restoration and conservation efforts. By identifying thresholds for key ecosystem functions, such as biodiversity, water quality, increment in dry areas, and increments of cocoa diseases, they can prioritize restoration actions in areas that have crossed critical limits, intervening, for example, by implementing methods of agroforestry and other nature-based methods, and intervening on EE species. Conservation measures can be designed to ensure that the involved ecosystems remain within healthy and functional states;
- *Multicultural and Social Dimensions*: Understanding thresholds may contribute to building resilience in multicultural social landscapes. By identifying the range of conditions within which a system can maintain its desired state, the involved actors (NGOs, school managers, social researchers, politicians, etc.) can implement adaptive social strategies. This involves adjusting practice in teaching, taking initiatives of cultural exchange, increments of multicultural events, informational speech and courses, campaigns of literacy, training courses, workshops on Africa culture, and promoting discourses to change the perception of female gender, in order to bring social dimensions back within "safe limits".
- *Economic Production*: Managers can monitor key variables and indicators that are relevant to economic and production activities. When these variables approach critical points, the early warning system can notify the actors (farmers or cooperatives, cocoa processors, NGOs, local authorities, managers), enabling them to take appropriate actions promptly. Such actions might include adjusting production, intervening in specific crops areas (satellite data analysis), reallocating resources, implementing risk management strategies, or making informed shared decisions based on the indications provided by the DSS;
- *Policy and Planning*: Incorporating thresholds into management decisions helps to inform policy development and land use planning processes. Policymakers can set guidelines, regulations, and targets that aim to prevent ecosystem degradation and maintain land health over the long term.

Finally, the variables are examined in the time and interpreted with consideration given to their change over a prolonged period (cf. Suarez and Oliva 2005).

- Regular: the variables show no significant variations over time;
- Hyperturbed: the variable is subject to repetitive positive and negative changes, or back and forth transitions between adjacent levels;
- Specific shock: the variables undergo a sudden change;
- Disruptive: the change is evident but only in one dimension;
- Avalanche: changes involve multiple dimensions with cascading effects.

Using this framework and our machine learning models, which establish connections between independent (data source) variable, and nonlinear dependent state variables, we are able to interpret and understand the type of transition taking place. This allows us to comprehend what is happening in broader or local terms in the digital, agricultural and multicultural dimensions, actively intervene to provide support throughout the process, and manage the transition at multiple levels.

5.8. Transition Management

Transition management in ecological landscapes involves long-term processes. According to (Geels 2002), transitions are gradual processes that unfold over a span of more than 25 years, hence they necessitate a strategic perspective. However, a successful implementation of a transition also entails short- and medium-term tactical and operational decisions in the midst of uncertainties and challenging questions. It is crucial to monitor the ongoing processes and engage in continuous reflections on the decisions taken. In short, transitions require management. Following the indication provided by (Loorbach 2010), we divide the transition management in four key governance activities: strategic, tactical, operational, and reflexive (see Figure 10).

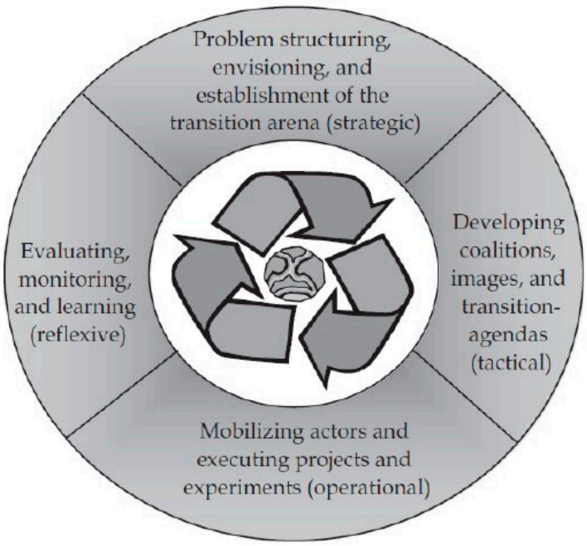

Figure 10. The transition management cycle as proposed by Loorbach. It consists of four key activities: strategic, tactical, operational, and reflexive. (Source: Loorbach 2010).

Strategic activities: define the major problems, develop a long-term vision, and formulate long-term goals and a roadmap. Strategic decision making ensures alignment with broader societal objectives and facilitates the mobilization of resources and support.

Tactical activities: build coalitions and transition pathways based on the long-term vision. These activities focus on developing short-term agendas and identifying key stakeholders. Problem specification, vision development, transition paths and agendas must involve collective deliberation and learning processes that align the perspectives of all stakeholders.

Operational activities: realize bottom-up transition experiments and mobilize transition networks while expanding the participation of actors. The transition pathways and agendas developed in the tactical phase guide the identification of short-term actions and bottom-up experiments that promote progress along the transition paths outlined in the agendas. Efforts are made to scale up transition experiments by involving a broader network of actors external to the project, thus expanding participation. A time-oriented agenda with precise milestones and internal dependencies is critical for this activity.

Reflexive activities: in transition management, these involve monitoring, evaluating and learning from experiments. Learning lessons is a crucial activity. Based on the results, adjustments are made to the vision, agenda and coalitions.

In essence, this framework takes a proactive and precautionary approach, empowering stakeholders to make decisions that promote the sustainable functioning and resilience of ecosystems. It fosters social inclusion, facilitates multicultural collaboration, enhances cross-linguistic activities, supports gender-sensitive interventions, and encourages cultural discourses that drive improved ecological practices. By adopting this framework, we seek to contribute to the socio-technological transition and design a comprehensive methodology for ecological sustainability and inclusive development. Transition management activities provide the structure necessary to effectively manage and control the transition process on multiple levels.

6. Discussion and Conclusions

This article presents the "Abidjan cocoa project" within the context of an EU−African cocoa supply chain. It discusses the challenges and solutions, considering the local capacities and possibilities of operating in a linguistically and culturally inhomogeneous context. The goal of the project is to make the technological aspects of implementing new ecological production methods acceptable to the local population by also pursuing goals of social inclusion, gender respect, literacy, ecological education and training.

The cocoa market in Côte d'Ivoire is regulated by the Coffee−Cocoa Council (Le Conseil du Café−Cacao), a government agency that is the only entity legally authorized to trade with buyers: the cost per metric ton of cocoa is determined by the Council.

Cocoa farmers struggle for a fair wage, with millions surviving on an average of only $0.78 a day, according to the World Economic Forum (Aljazeera 2022). Farmers and cocoa processors are advocating for changes in their working conditions and seeking higher incomes for daily labor (NY Times 2022).

On the other hand, cocoa production (cocoa bean cultivation) is currently facing a shortage due to reduced rainfall (Africa News 2022).

Discussing ecological transition with individuals who are struggling daily to improve their livelihoods and escape poverty is not always a straightforward task. It is crucial to consider justice and equity, particularly gender equity, alongside fair working conditions, revenue growth, feasibility of processes, transition costs, and training capacity. In all of this, cross-cultural understanding and social dimensions can be an accelerator or an obstacle to the acceptance of the transition.

Therefore, the term that deserves emphasis is "just". For the transition to be equitable and just, and for its effects to last, it must be embraced and socially inclusive (OECD 2017). In our case, a just transition entails a shift from misguided and aggressive intensive production methods to a production approach that is integrated with the environment and society, while respecting economic and cultural aspects.

The Abidjan project involves the establishment of an agroecological school with a living lab. The school hosted and directed by the Communauté Abel in Abidjan has a connection to the Gruppo Abele Foundation in Turin, Italy (www.gruppoabele.org accessed on 29 June 2003). The Communauté Abel has been operating in Abidjan for more than 40 years. With its network of contacts with farmers in the cocoa chain, associations, local authorities, and local organizations, this institution provides a suitable environment for collaborative initiatives. The Communauté Abel school in Abidjan is dedicated to pursuing goals of social inclusion, literacy, job training, and women's gender empowerment. It also offers hands-on experiences and training to students on ecological methods of cocoa cultivation and processing through its living lab and agroecology courses. The agricultural school serves not only as an education tool, but also as an instrument of cultural mediation, bringing together people of different ethnicities, cultures, and social backgrounds.

The school's focus has traditionally been placed on the socially disadvantaged, particularly women, with an emphasis on their potential to receive training and pass on knowledge to future generations. In Africa, women are often still relegated to the role of "household keepers", which deprives them of freedom, literacy, independence, and basic rights. The schools introduce women to new jobs, offer literacy programs, provide them with practical skills to achieve labor-related and economic independence, furthering their empowerment.

Technological advancements enable transformative changes in the territory, such as the assessment of groundwater levels and the identification of areas affected by drought and deforestation. Moreover, technology can assist cocoa farmers in their cultivation efforts by detecting plant diseases and pinpointing areas that require intervention.

These capabilities are made possible through the utilization of open-source data from Copernicus-2, GRACE (NASA), and ERA5, as well as the use of low-cost ground sensors. Close-up images captured by drones or farmers' cell phones further contribute to the analysis.

Satellite data and ground sensors enable survey methods to monitor land using vegetation indexes (VI). Advanced combinations of convolutional neural network (CNN), long short-term memory (LSTM) neural networks, and ERA5 data are used to cast hydrologic models for groundwater forecasting and aid in identifying future extreme events. Disease identification methods use close-up imagery and state-of-the-art recursive neural networks (RNNs).

Our framework follows a multifactorial, multilevel vision (Geels 2002). It allows us to monitor economic, social, cultural, infrastructural, and technological variables. A threshold approach (Groffman et al. 2006; Zhang et al. 2018) is applied to the variables of interest, providing a comprehensive decision-support tool that offers managers, NGOs, farmers, local authorities, and local cooperatives in-depth criteria and comprehensive tools to decide when and where interventions are needed.

Transition management activities (Loorbach 2010) ensure that the transition processes are guided by a strategic vision, encompassing tactical activities, operational activities, and reflexive learning processes. Following a multi-level perspective approach to transition, our framework offers control and oversight of socio-technological transitions in ecological contexts.

By using low-cost technologies and open-source software, along with our freely usable classifiers and forecasters, and accessing open satellite data (Copernicus-2, GRACE, ERA5), as well as employing a digital twins approach, we aim to keep costs low and make these technologies accessible to cooperatives, farmers, local authorities, and NGOs. This accessibility is particularly important in a developing economy.

The objective of the project at this stage is to enhance the skills and capabilities of the agroecological school. The approach involves establishing a robust foundation, through interdisciplinary collaboration, fostering cohesion and social justice, and concurrently increasing the capacity to reduce the carbon footprint associated with cocoa processes. The ultimate goal is to empower individuals, with a particular emphasis on women.

The project is in the middle of its second year out of four years of planned actions and is encountering some economic obstacles. It is believed that production can achieve greater economic sustainability by acting in two directions: first, by strengthening the capacity to process cocoa in a commercial product for the Ivorian territory, and second, by expanding the reach of processed products in Europe to tap into new markets for local processors and retailers. One useful way of achieving these objectives is to create a bridge of opportunity for commercially useful relationships between African and European companies within the existing supply chain. This approach would facilitate the growth and advancement of local businesses through various avenues, including strengthening supply partnerships, facilitating import−export activities, and establishing franchise relationships.

The development of an eco-equal solidarity agroecological schools on Ivorian territory, augmented by technological means and a solid socio-technological transition framework, will serves as a driving force for a long-lasting African−European relationship that ensures a just ecological transition, with multicultural understanding, social justice, and economic benefits for both continents.

Author Contributions: Conceptualization, S.P. and R.M.; methodology, S.P. and R.M.; software, M.S. and G.S. validation, R.M., S.P., M.S. and G.S.; writing—original draft preparation, S.P. and R.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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